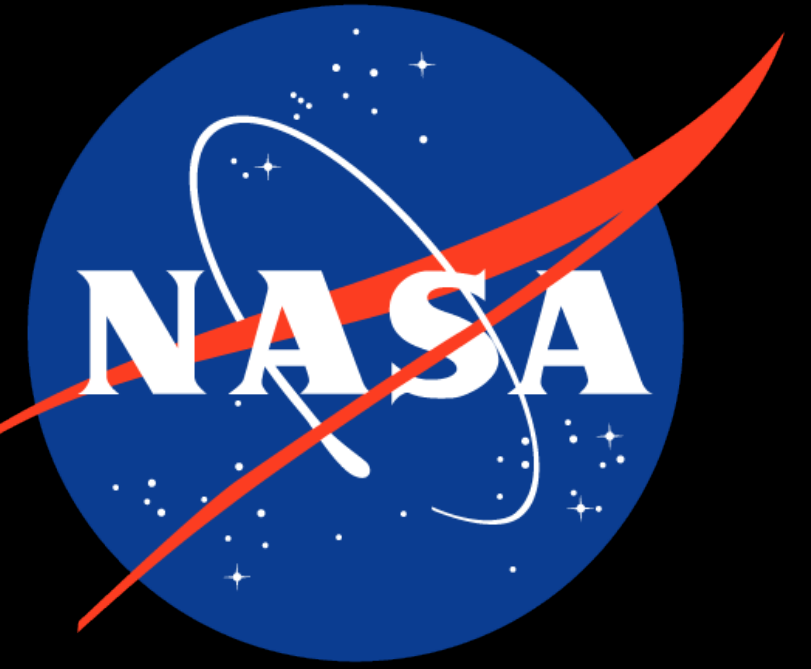


A COMPARISON OF VAN ALLEN BELT RADIATION ENVIRONMENT MODELING PROGRAMS: AE8/AP8 LEGACY, AE9/AP9, AND SPENVIS

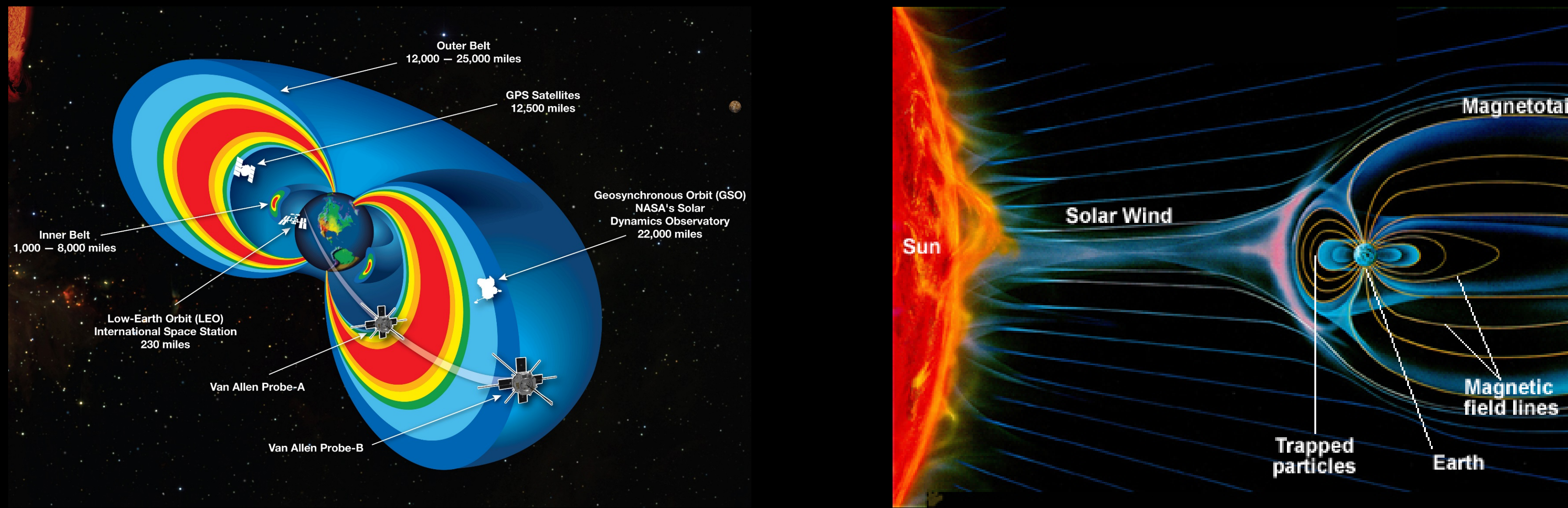
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Introduction

The Van Allen Belts, an active radiation environment consisting mostly of electrons and protons that have been trapped by Earth's magnetic field, have the potential to gravely damage man-made satellites in orbit; thus, proper precautions must be taken to shield NASA's assets. Utilizing data that has been collected by satellites over decades of space flight and using theory to fill in the gaps, computer models have been developed that take in the orbital information of a hypothetical mission and output the expected particle fluxes for that orbit. However, as new versions of the modeling system are released, users are left wondering how the new version differs from the old. Therefore, we performed a comparison of three different editions of the modeling system: AE8/AP8 (legacy), AE9/AP9, and the Space Environment Information System (SPENVIS).

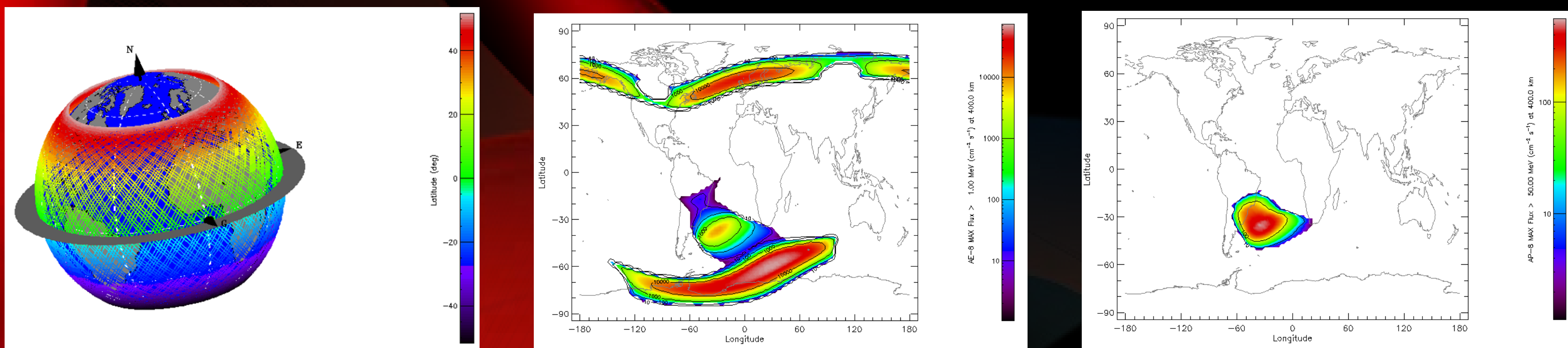


The image on the left depicts the Van Allen Radiation Belts around Earth along with the approximate orbits of well known spacecraft. The image to the right shows how solar winds warp Earth's magnetic field and, consequently, the charged particle radiation trapped within the field.

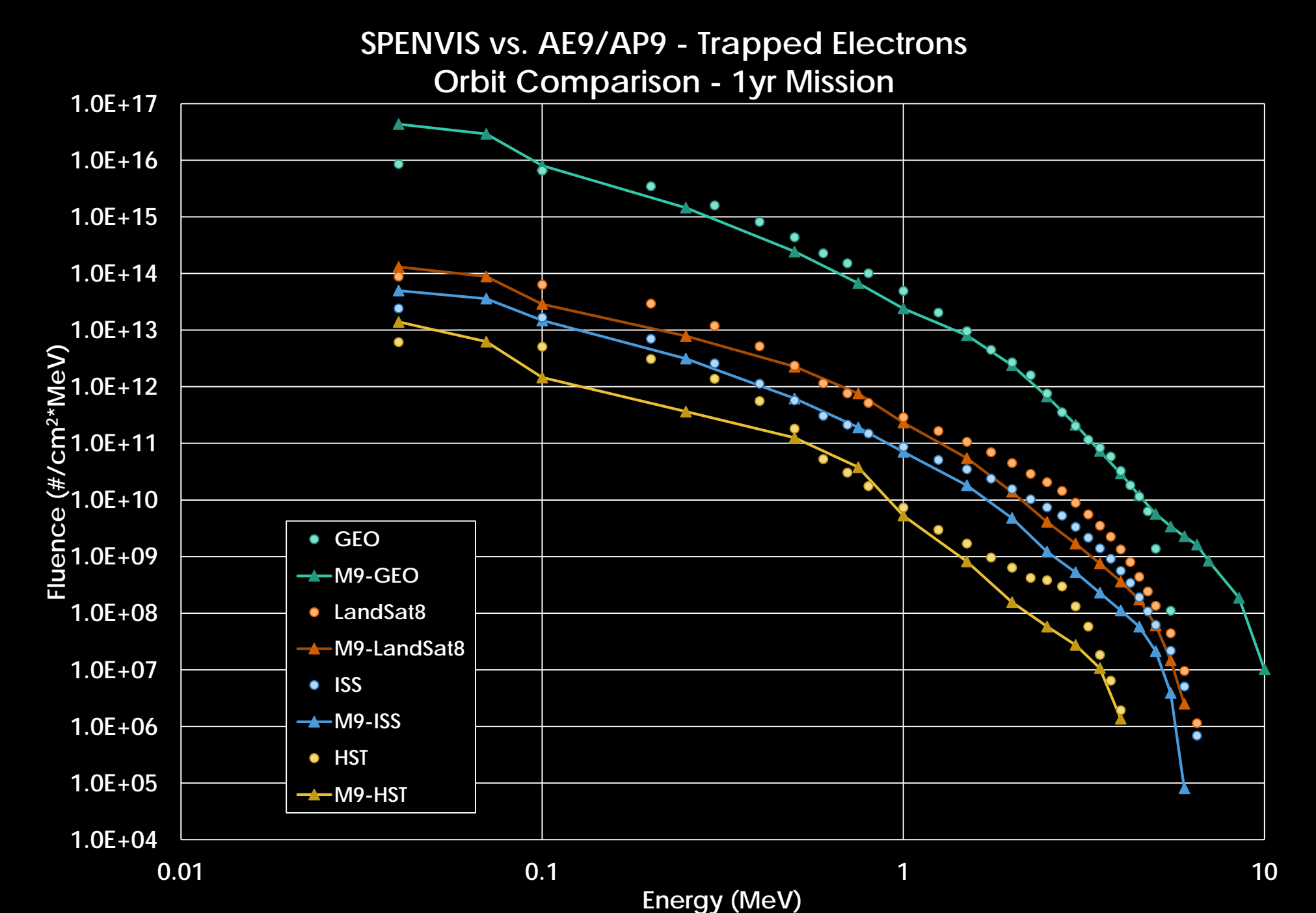
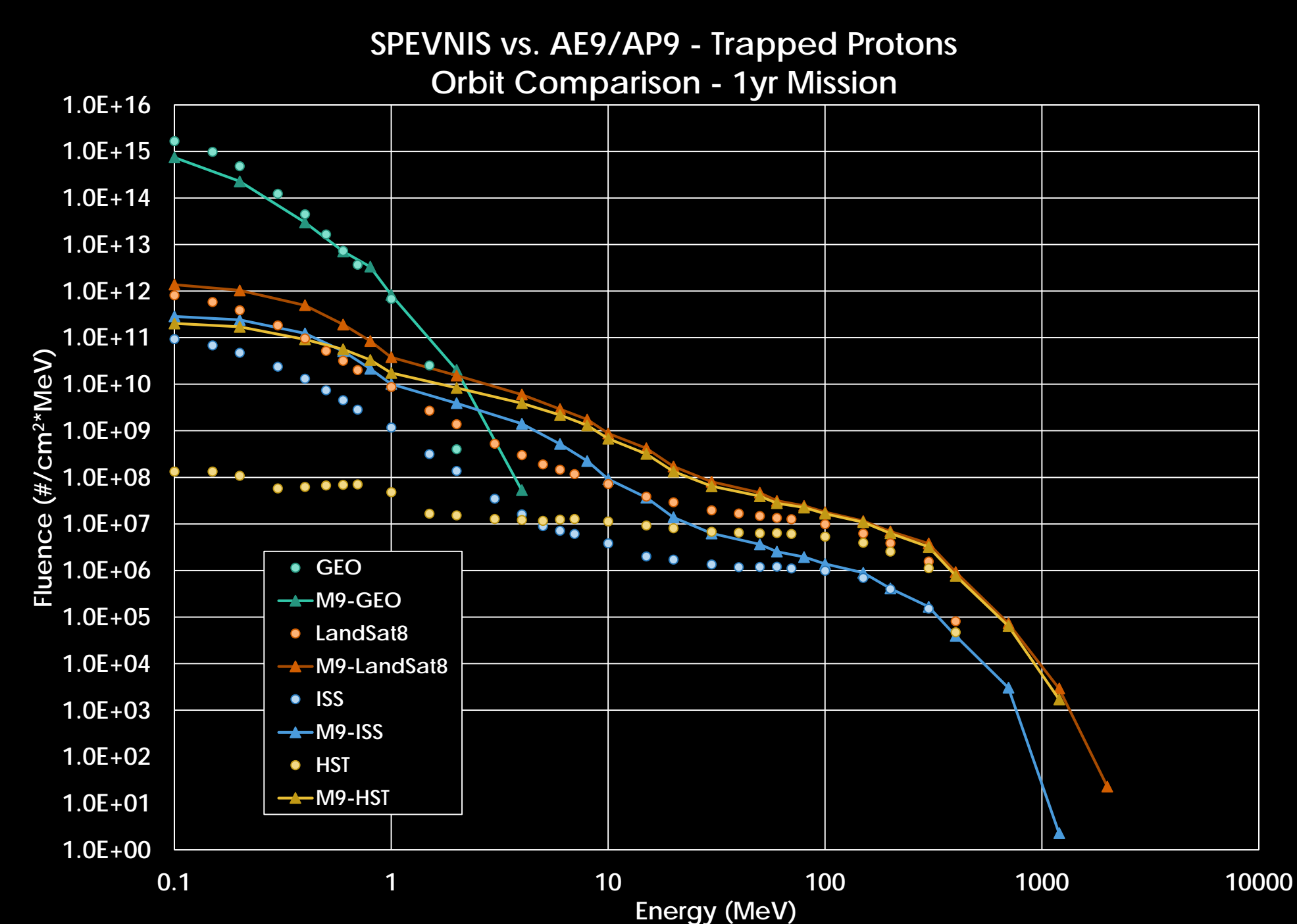
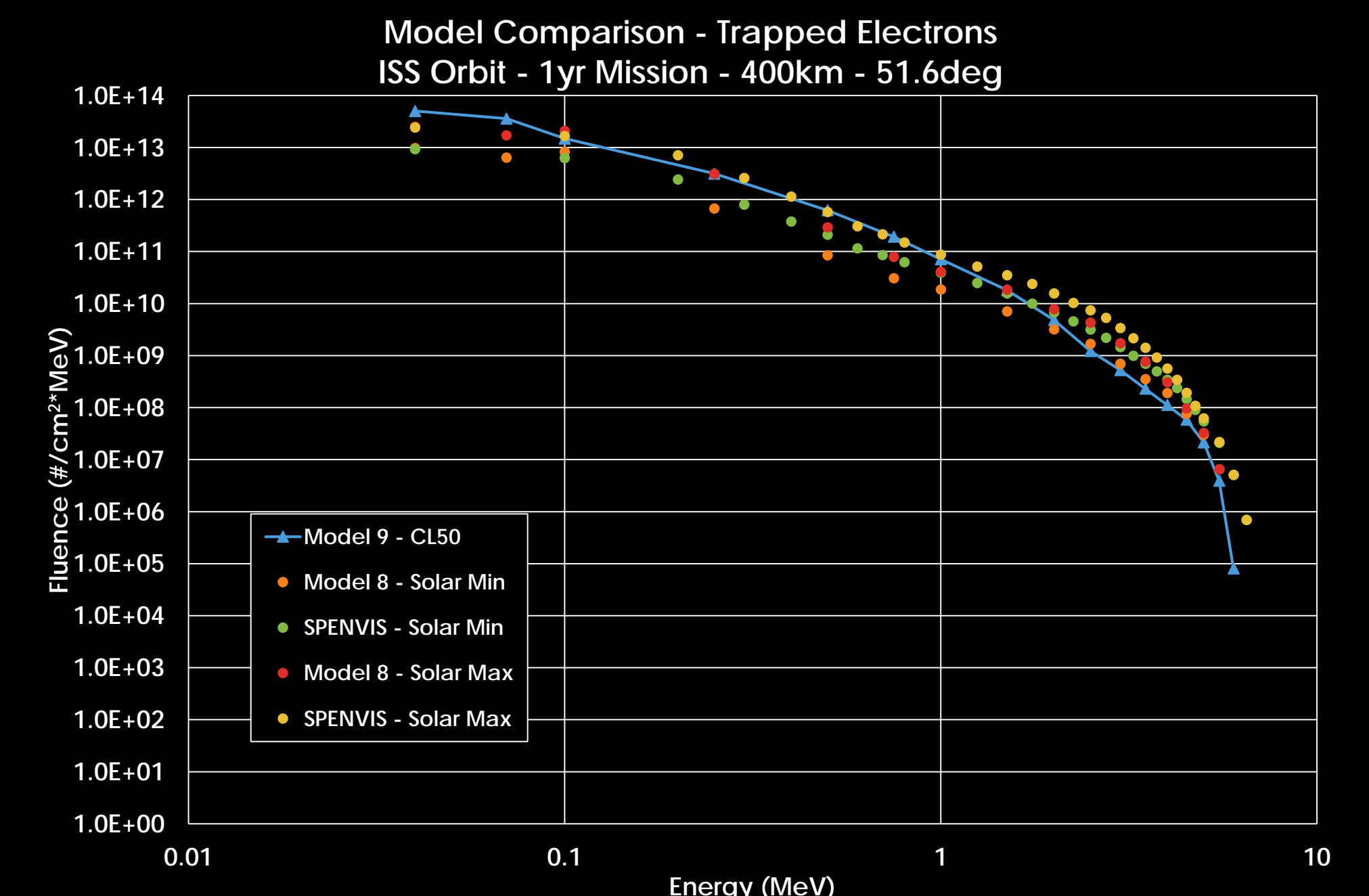
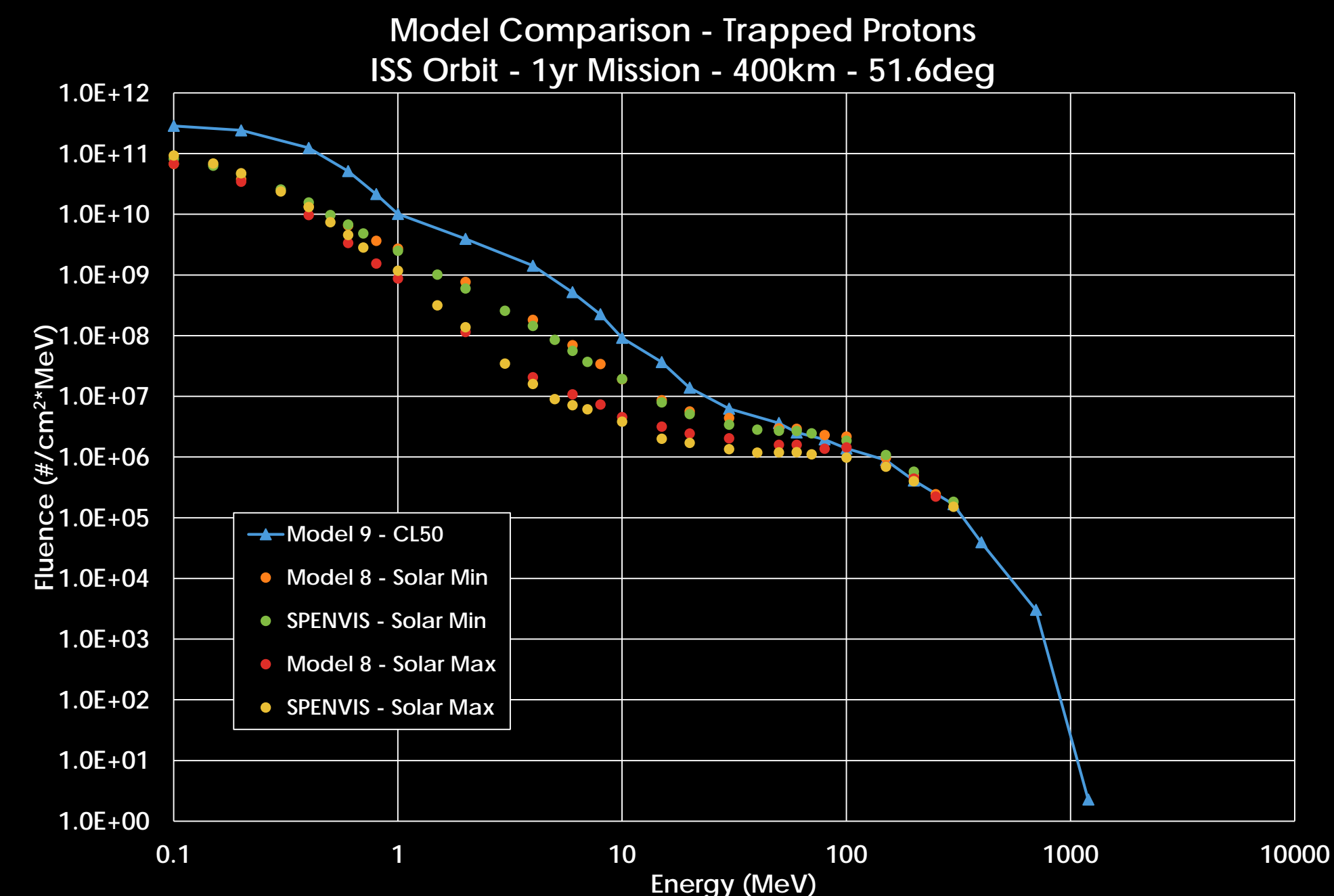
The Models

When attempting to determine the amount of dose accumulated from the particle radiation in the Van Allen Belts and, subsequently, how much shielding is needed to protect the satellite in construction, SPENVIS is the baseline model used by NASA engineers to determine the particle fluence at a given orbit. SPENVIS is an online version of AE8/AP8 developed primarily by the European Space Agency who altered the original code to extrapolate data to obtain fluence measurements at higher energies. Therefore, we wanted to compare SPENVIS to AE8/AP8 (legacy) to determine to what extent was the model altered. We also wanted to determine how the newest model, AE9/AP9, with its Monte Carlo capabilities and updated environmental data, differs from model-8 (legacy) and SPENVIS. The Monte Carlo mode of model-9 accounts for the uncertainties in the fluxes that are due to measurement and gap-filling errors as well as including an estimate of variations in the radiation environment due to space weather events. However, the largest difference between these models comes from their utilization of different magnetic field modeling subprograms. For example, SPENVIS and model-8 (legacy) use the Jenson and Cain 1960 internal field model for AE-8 Solar MAX and MIN and AP-8 Solar MIN while also using Goddard Space Flight Center 12/66 field model for AP-8 Solar MAX^[1], where as AE9/AP9 uses International Geophysical Reference Field model for the main magnetic field and Olson-Pfitzer Quiet model for the external magnetic field^[2].

It is also important to note that the version of AE8/AP8 (legacy) that we used for our comparisons is included as an option in the AE9/AP9 graphical user interface; therefore, it is not an entirely independent version. However, since the model-8 (legacy) uses the same magnetic field models as SPENVIS rather than the ones used by model-9, this should have little affect on the outcome of the assessment.



This image to the left shows the approximate orbit of the International Space Station around Earth. The contour map in the center depicts the trapped electron radiation flux levels at the altitude of the International Space Station (400km), while the contour map on the right shows the trapped protons radiation flux levels.



Results

The graphs above represent a synopsis of the comparison of the three editions of the radiation environment modeling system. In the top left graph, in which proton fluences from all three versions are compared at the orbit of the International Space Station, the differences between SPENVIS and model-8 (legacy) are small. And, what differences there are can be attributed to the fact that when calculating flux SPENVIS performs calculations for 10 days then extrapolates the data to the length of the entire mission, in this case one year, while when using the legacy version of model-8 we calculated the flux for the entire year rather than extrapolating. Therefore, this tells us that **despite the changes to the original coding, SPENVIS and AE8/AP8 (legacy) are virtually the same** with the exception of higher energies provided by SPENVIS. Interestingly though, the **proton fluences from the AE9/AP9 are orders of magnitude higher than the predicted fluences of the model-8 versions**. This is an important result because protons can be highly penetrating and, thus, damaging to equipment and people, especially at high energies. Furthermore, in the graph in the bottom left we see further evidence that **AE9/AP9 is predicting higher proton fluxes than model-8 particularly for low-Earth orbits** such as those of the ISS (400km), the HST (540km), and LandSat8 (700km). For electrons, however, shown in the right two graphs, although the estimates seems to be much closer than those for protons, the general trend seems to be that model-9 is predicting just slightly lower electron fluence than model-8.

In future studies, this anomaly in the prediction of higher than expected proton flux should be looked into further in order to narrow down the range of orbits at which the differences occur. Also, the dose accumulated from the protons at said energies should be calculated to determine if this proves to be a danger to NASA's assets in space.

Acknowledgements and References:

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[1] Lauenstein J.-M. and Barth J.L., "Radation Belt Modeling for Spacecraft Design Model Comparisons for Common Orbits," *IEEE REDW*, pp.111-117, 2005.

[2] "AE9/AP9/SPM Radiation Environment Model: User's Guide," Version 1.30.001, pp. 50, 2016.